Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at http://about.jstor.org/participate-jstor/individuals/early-journal-content.

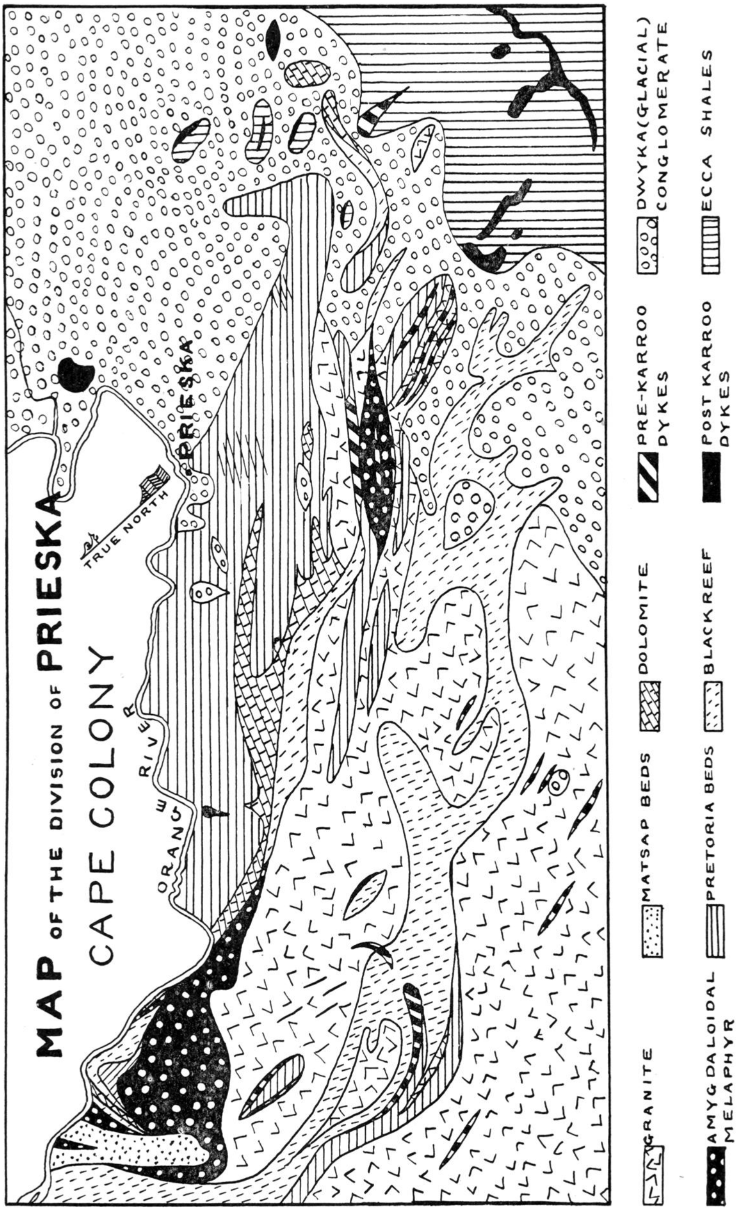
JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact support@jstor.org.

THE PROBABILITY OF LARGE METEORITES HAVING FALLEN UPON THE EARTH

PROFESSOR E. H. L. SCHWARZ, A.R.C.S., F.G.S.
Rhodes University College, Grahamstown, Cape Colony

From time to time the accumulation of new facts in any one science renders it necessary to examine into the cause for the existence of certain features, and to see whether some small points which rendered the earlier explanations not altogether satisfactory, may not be entirely accounted for in the light of the new experience. In many cases this proceeding has resulted in the entire recasting of our ideas concerning certain phenomena, especially in the physical sciences where laboratory demonstration can prove the truth of the new law; in geology, the unwieldy nature of the subject-matter, and the different aspects which the same country or mountain may present to different observers, renders this method somewhat unsatisfactory. It must, however, be done, if the science is to progress, although in the end a categorical statement that the new explanation is a true one, and the old one a false one, cannot be made. It is the purpose of this paper to pick out certain facts in connection with the amygdaloidal lavas of Prieska, Cape Colony, which cannot readily be explained on any of the theories of igneous extrusion, and to see whether they cannot be accounted for on some other theory; I shall summarise what is known of the fall of large meteorites and point out in what way the phenomena connected with these show certain significant resemblances to those exhibited by the amygdaloids of Prieska, tentatively suggesting that in the past huge bolides fell on the earth, melted the rocks in the neighborhood of the fall and produced these great fields of lava.

The meteorites that we examine in the collections of museums are small and would not by their fall make much impression on the earth: it is true that in the course of ages these small meteorites must add considerably to the bulk of the earth for it is estimated that some hundred thousands, if not some millions, of meteoric bodies fall upon the earth each day. Even these museum-specimen meteor-


MAP OF THE DIVISION OF PRIESKA
CAPE COLONY
TRUE NORTH
PRIESKA
ORANGE RIVER
GRANITE
AMYGDALOIDAL MELAPHYR
MATSAP BEDS
PRETORIA BEDS
DOLOMITE
BLACKREEF
PRE-KARROO DYKES
POST KARROO DYKES
DWYKA (GLACIAL) CONGLOMERATE
ECCA SHALES

ites, as I may call them, range up to sizes which would shake considerable areas of country by their fall, as for instance the Bacubirite meteorite, which is thirteen feet long and is estimated to weigh 50 tons.[1]

In the Coon Butte, Ariz., there is a crater which was described by Gilbert as volcanic, but subsequent investigation has failed to discover any volcanic material connected with it; on the other hand, strewn round it are masses of meteoric iron of which ten tons have been carried away at different times and now figure in collections as portions of the Canyon Diabolo meteorite. The rocks in the vicinity of Coon Mountain consist of horizontal beds of Aubrey limestone and sandstone belonging to the upper Carboniferous series. The mountain is formed by the up-turned edges of the strata making a jagged circular ridge varying in height from 120–30 feet above the plain. The chasm is 600 feet deep and 3,800 feet across. The nearest lava flows and cinder cones are twelve miles distant, while the San Francisco mountains which contain many volcanic cones are 45 miles away. The material at the bottom of the crater has been investigated by Messrs. Barringer and Tilgham by means of bore-holes down to 1,000 feet, and the rock encountered is mostly pure white silica which in some places is in the form of impalpable powder; scattered throughout this there are masses of varying sizes of pumiceous and more compact material, which chemical and microscopic examinations show to have been formed by the crushing and fusing of the quartz sandstone. Below the zone of crushed and fused material there is an underlying sandstone quite intact and unaltered.[2]

There seems to be no reasonable doubt that this crater is actually the result of the impact of a huge bolide and the absence of the large meteor itself is explained by supposing that the heat of the impact was sufficient to melt and perhaps vaporise its substance; certainly there is a large quantity of magnetic iron oxide lying as dust about the neighboring country, which, on analysis, gives a notable percentage of nickel.

---

[1] H. A. Ward, "The Bacubirite Meteorite," *Proc. Rochester Acad. Sci.*, 1902, IV, p. 67.

[2] D. M. Barringer, "Coon Mountain and Its Crater (Arizona)," *Philadelphia Acad. Nat. Sci. Proc.*, 1906, LVII, p. 861; B. C. Tilgham, *ibid.*, p. 887; G. P. Merrill, *Smithsonian Miscellaneous Collections* (quarterly issue), L, 1907, pp. 203, 461.

A large meteor need not necessarily be an iron one, and we have a remarkable block of melilite-basalt in Cape Colony which has certain features that point to its possible meteoric origin. The occurrence is at the top of the Spiegel River Valley in Riversdale; the outcrop of the rock is about 100 feet in an east-and-west direction, and half as much across, though, as it is found at the top of a hill, and the sides are strewn with débris from it, it is hard to determine the exact size of the block; there are bands of harder and softer material in it which give the mass the appearance of being bedded, and the dip is some 15° to the southeast. It is surrounded on all sides by coarse, loose conglomerates of Cretaceous age which show no disturbance whatever. Had the mass come up in a volcanic throat, one would have expected to see some evidence of the explosive force in the loose gravel, or some lateral dykes or fume vents, but nothing of the sort could be found, and no other volcanic rocks occur within many miles. The view adopted by the Geological Survey[1] is that it is a volcanic pipe filled in, but that is simply because no similar blocks have been described with which to compare it whereas melilite-basalt ordinarily occurs in connection with volcanoes.

If we turn to the moon whose surface being free from erosion and deposit should show clearly any marks made on it by the fall of meteorites, we find certain evidence which is highly suggestive. The craters which are scattered so freely over the moon's surface were thought by Gilbert[2] and others to be due to the impact of meteors; that they were not so formed we gather from the following considerations. In some of the craters the floor or top of the lava column stands many hundreds of feet below the general level of the surface, but in others the floor is as much above that level. The internal walls of the craters show definite terraces like old strand lines which have been formed by the successive retreat of molten material within the volcanic chimney. The craters, especially the smaller ones, often lie upon definite lines of fissures like the volcanic fissures of Iceland, an arrangement which would have been impossible had they been formed by the infalling of meteors. Lastly there is a regular scale of dimensions corresponding with antiquity in the craters, the larger being the older and the smaller ones successively younger; this we can establish both from the fact that the smaller ones often breach the larger ones, as well as from the freshness of the rocks about the smaller ones as compared with those surrounding the larger ones; for although there is no atmospheric weathering in the moon, the alternate heating and cooling of the surface brings about a certain amount of alteration which in time produces sufficient effect to be clearly noticed through the great telescopes.

---

[1] A. W. Rogers and E. H. L. Schwarz, *Ann. Rept. Geol. Comm.*, 1898, Cape Town, 1900, p. 62.

[2] G. K. Gilbert, *Bull. Phil. Soc. Washington*, XII, p. 241.

These craters do not belong to volcanoes such as exist on the earth but resemble rather the outbursts of entangled molten matter during the final consolidation of the moon, according to Professor T. C. Chamberlin's view,[1] and on such a theory the graduation in size is well accounted for. But after this stage was over, when the forces which brought the molten material from the interior to the surface had become spent, no matter what their actual nature was, then the surface of the moon was deluged with floods of lava, which, over tracts many hundreds and thousands of square miles in area, obliterated all pre-existing features and in their margins invaded and ruined the craters which stood in the path of the molten liquid. These *Maria* or dark patches of the moon occupy roughly one-third of the visible portion, and as seen through the great telescopes which bring the moon's surface to within 40 miles of the observer, their margins show that the material of which they are composed flowed in upon the rough ground as very liquid lava would do. It fills in the lower ground forming numerous bays, and in many instances, as is the case of the crater Doppelmeyer, it distinctly appears to have melted down the side of the crater-wall next to it and to have filled in the cavity to its own level. This feature is not confined to any one spot of any one *mare*, but is to be noticed throughout the several thousand miles of the extent of the margins, and leads one to the conclusion that the *maria* were formed by a once fluid matter of the sea inundating firm land. The quantity of igneous matter was very great, and in each *mare* or sea it seems to have appeared all at once, there being no mark of successive flows such as compose the extensive lava fields of the earth. The lava of the several *maria* never overlap, although the

---

[2] T. C. Chamberlin and R. D. Salisbury, *Geology*, II, p. 105.

gravitative attraction on the moon being only one-sixth what it is on earth, would allow very steep slopes at the front of even fluid lava flows. The origin of this lava is still hypothetical, but it is to be noticed that none of the volcanoes of the moon give forth freely flowing streams of lava, nor do any of the numerous fissures or faults on the lunar surface, some of which evidently penetrate deeply, distinctly give rise to lava flows; generally it is established that all the volcano-like openings appear always to have retained their lavas within or near their walls, or, in other words, there was no tendency for lava to pass up to the surface in large quantities.

There is no evidence in any of the *maria* that the lava came up from a central pipe or from an elongate fissure; the general form of the seas is rounded or oval, and it would seem to indicate that if the fluid came from within, the lava should have emerged as from a terrestial volcano pipe, for if it came from fissures these should have been of elongate shape. But if the lava came either from fissured or from pipe-like openings there should be a grade to the flow extending from the center of the field to its margin; owing to the slight value of gravitation this grade should be steep. There, however, is no trace of such a slope; on the contrary, the curve of the margin of illumination shows the surfaces of the *maria* are essentially horizontal.

The hypothesis which fulfils most of the conditions of the case with respect to the origin of the lava of these *maria* in the moon is that great meteors fell upon the moon and by their impact produced sufficient heat not only to melt up their own substance but a good deal of that comprising the adjacent lunar surface. Even beyond the seat of impact, the shearing strains would probably be sufficient to convert much of the material of the surface into a fluid state, with the result that a mass of lava of a very high temperature, equal at least to the bulk of the invading body and probably several times as great, would be sent radially from the point where the impact took place. The evidence of melting effected by the material which forms the plains of the *maria* is considerable at several points, notably in the case of the craters on the margins of the seas. It seems quite certain that the walls of these craters next the sea have been in some manner effaced by contact with the material which came against it; in the case of the crater Flamstead in the Oceanus Procellarum, the crater-wall has been almost melted down, but still rises slightly above the surface of the inundation; good examples are also seen in the Mare Tranquilitatis, Fig. 1. At many points the material forming the *mare* comes against extended steep-faced cliffs, which have the same general character as the inner slopes of the great craters, where the form of the declivity certainly has been determined by the melting action of the lava of the base. Further, where there are depressions in the area in the borders of the *maria*, the material of which they are composed flows into them as a fluid would have done.

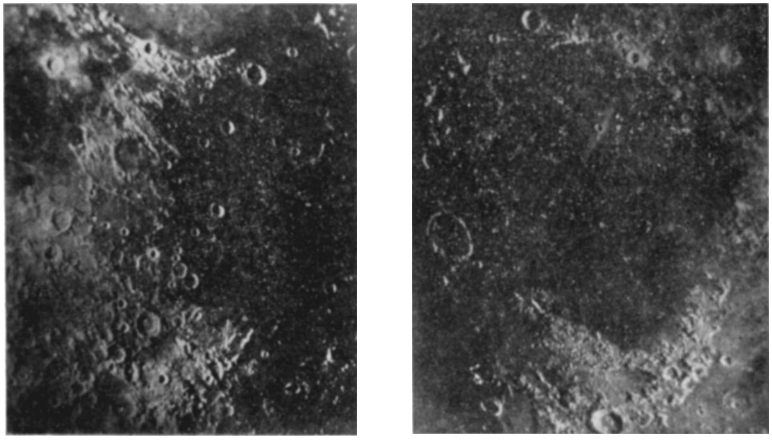


FIG. 1 FIG. 2

PHOTOGRAPHS OF THE MOON'S SURFACE, AFTER N. S. SHALER

FIG. 1.—Mare Tranquilitatis with Mare Serenitatis in the upper portion of the plate, showing the margin invaded by lava floods.

FIG. 2.—Mare Serenitatis, showing on the left the large crater Posidonius and above it the crater le Monnier which has part of its wall broken down by the lava of the *mare*.

The great objection to the hypothesis that the *maria* were formed by molten rock produced by the impact of large bodies falling upon the surface of the moon is that similar bodies competent to generate a great deal of heat have not fallen upon the earth's surface in the time which has elapsed since the beginning of the geological periods; there is so far indeed no recorded geological reason for supposing that they have ever fallen upon the planet, but it is just such evidence that I wish to submit. It must, however, be remembered that the moon's surface took its shape long before the beginning of our geological record, so that if such evidence is to be found on the earth, such lavas of extra-terrestrial origin must be among Archaean rocks, where the unraveling of the tale would be extremely difficult, or they would be hidden under superincumbent strata. It is to be noted also that even in this stage of the evolution of our solar system there remain bodies in order of size such as would in falling upon the surface of the larger spheres produce the effect which we observe in the *maria;* thus the group of asteroids between Mars and Jupiter, though generally of far greater mass than would be required by impact to melt the larger of the *mare* fields, probably contains many bodies which in case of collision with our satellite would bring about the consequences which can be noted. At least one such mass of matter, Eros, has recently been discovered at no great distance from the earth.[1] It is probable that in a former state of the solar system when the moon was assuming its present surface features, these detached masses of matter were more abundant than they are at present. The tendency would be for those near the great spheres to be drawn in upon them, with the result that they would become rarer near the planets and the larger satellites.

Having then established the fact that giant meteors may have fallen on the earth and may have melted up tracts of country which would be deluged with lava without apparent vent or orifice from the interior, we can legitimately inquire whether there are any evidences of such occurrences on the earth's surface ? There are many vast tracts of lava known on the Earth which offer tempting fields for speculation in this connection, such as the great lava sheets of the Snake River in Idaho, the Deccan traps of India and the Kapte Plains of British East Africa, and even the occurrence on these of small cinder cones and beds of ash and tuff does not necessarily prove that the material came from the interior of the earth, any more than the small blister cones on a flow of molten iron prove that the subjacent floor is riddled with blowholes, but I wish in this introductory statement to confine my remarks to one field which I know thoroughly.

In the district of Prieska, south of the Orange River, there is a tract of country which has been cleared of its covering of glacial drift and stands today with many of the features which it presented in a remote geological period. The glacial drift is of Permian age, and the topography revealed with astonishing freshness, belongs to that or earlier epochs. The area was described by Dr. Rogers and myself in 1899[1] and consists of a base of granite on which rest the various formations of the Transvaal System, quartzites, dolomites, and banded jaspers, and the Matsap or Waterberg sandstone, unconformably above these. The rocks present a bewildering number of correlation difficulties and nearly all the low-lying ground is covered with the red Kalahari sand which obscures the junctions of the several systems of rocks. There are no rivers or stream beds with the exception of the Orange River, and all the water precipitated in the rare rains sinks through the sand and evaporates slowly leaving behind a crust of calcareous sinter. Weathering therefore is of the desert type, and the breaking down of the rocks is nearly entirely brought about by expansion and contraction, without chemical change of the constituent minerals. For this reason the less compact Permian and Triassic clays and shales of the Dwyka and Ecca Series have yielded easily to the forces of destruction and have been blown away; the underlying rocks, however, of dense crystalline structure or of compact metamorphic nature, have emerged with relatively slight alteration from their burial beneath the Karroo rocks. The younger rocks were invaded by dolerite intrusions belonging to the great system of dykes and sills that extends right across South Africa almost from sea to sea, but the older are penetrated by a number of dykes of the most varying types which have been altered by crushing and metamorphic action generally so that they can be described as diabases, granulites, hornblende-schists, and serpentine with chrysotile. Besides these last there is a third class of intrusive rocks which is, paradoxically, amygdaloidal.

---

[1] N. S. Shaler, "A Comparison of the Features of the Earth and the Moon," *Smithsonian Contributions to Knowledge,* XXXIV, No. 1438, Washington, 1903.

These amygdaloidal melaphyres are known throughout the region of the Palafric rocks, whether we trace them on the surface in the Colony, Bechuanaland, or the Transvaal, or encounter them in the depths in the mines of Kimberley. The main group of them occurs below the first member of the Transvaal Formation—the Black Reef Series—and was called by Molengraaff the Vaal River beds, but is now more generally known as the Ventersdorp beds. They consist of lavas of varying basicity ranging from melaphyres to felsites and rhyolites and are usually accompanied by enormous developments of agglomerate ranging from coarse boulder beds to fine volcanic ash.

---

[1] *Ann. Rept. Geol. Comm.*, Cape Town, 1900; see also E. H. L. Schwarz, *Trans. Geol. Soc. S. A.*, Johannesburg, 1905, VII, and A. W. Rogers and E. H. L. Schwarz, "The Orange River Ground-Moraine," *Trans. Phil. Soc. S. A.*, Cape Town, 1900, IX.

Two areas of these amygdaloidal melaphyres occur in the Prieska district under discussion, while other and smaller areas are to be found in the neighborhood. The largest of the masses is found to the north of the district on the farm Zeekoe Baard; it wraps round the end of the range of hills called the Ezel Rand composed of Matsap (Waterberg) sandstone and separates these rocks from the granite to the west and partially interposes between them and the Keis or Black Reef quartzites. There is a small mass also lying apparently intruded in the Waterberg sandstone. On the south side of the Ezel Rand there are some steeply inclined beds of limestone and quartzite which look as if they were the basal beds of the great limestone series turned up by force from the direction of the center of the igneous mass. Toward the point of the Ezel Rand there are tracts of agglomerate which probably belong to the melaphyre. The southern extremity of the melaphyre is on the farm Geelbecks Dam where it tapers out; the greatest width of the mass is on the farm Blink Fontein where it is 9 miles across, and the extreme length is 30 miles. A large portion of the area mapped in as melaphyre is, however, covered densely with red sand, through which the rock only crops out occasionally; on Schalks Puts and on the eastern part of Blink Fontein there are conspicuous ranges of kopjes formed of the rock.

The melaphyre is in contact with the Keis (Black Reef) Series of the farms Ezel Klauw and Louis Draai on the north, and with the Matsap (Waterberg) beds of the Ezel Rand, which it surrounds on three sides. To the south it is bounded by the Campbell Rand (Dolomite) Series on the one side and the granite on the other. The field-relationships are not compatible with the supposition that the origin of the melaphyre was volcanic, unless a group of faults is brought in to explain the contact of the amygdaloid with such a large range of rocks of widely separated ages; there is no evidence of such faulting, and although the rock is a typical lava, fine-grained to glassy in structure, and generally full of steam cavities, Dr. Rogers and myself were forced to the conclusion that the rock was an intrusive one and came into position after the earth movements affecting the Matsap beds had taken place.

About 30 miles in a southeasterly direction, reckoning from the southern extremity of the Zeekoe Baard mass, there is a second outcrop of amygdaloidal melaphyre on the eastern portion of the farm Jackals Water, and on the western part of the farm Prieska's Poort. The outcrop is elongated about 6 miles long and 1½ miles wide, trending northwest, the direction of strike of most of the Palafric rocks in the Prieska district. On the northeastern side the melaphyre is bounded by the granite of Prieska's Poort, and on the southeastern side by the Keis quartzites on the farms Jackals Water and Uitzigt.

Similar rocks in the neighboring districts which appear most certainly to be intrusive have strengthened the view that the Zeekoe Baard and Prieska's Poort amydaloids are instrusive, but against this we have the steam-holes and agglomerates—clear indications of volcanic origin.

If we accept the volcanic origin, then we must imagine that from a central vent or fissure some extremely fluid lava was poured out, which flooded all the low-lying country, wrapped round the hills, and finally cooled as a plain of lava. No known volcano fulfils these conditions, and from what we know of lava we would be inclined to state that such a mass could not be suddenly ejected at any one time, but would rather come up in separate flows, each of which would travel outward and downward and would cool long before it could wrap round the end of a range of hills such as the Ezel Rand, in the manner of a perfectly liquid substance. Then again we find the agglomerates at the periphery of the Zeekoe Baard mass, and here, also, to the north, there is evidence of thrust.

In whatever light we look upon these Prieska outcrops of amygdaloidal lava, confining our ideas to a terrestrial origin of the material, we come upon insuperable difficulties, but directly we admit the possibility of the fall of a meteor sufficiently large to melt up a portion of the earth's crust, all these difficulties vanish. The sudden development of a large quantity of liquid lava, the permeation throughout of steam holes from water contained in the rocks melted, the ridging up of portions of the periphery of the mass, the absence of true volcanic ash, but the great development of crushed up material entangled in molten rock—all these phenomena receive an adequate explanation on the meteor hypothesis. That the masses of lava often tail out into apparent dykes can be readily accounted for from the fact that earth movements have gone on since the development of the lava and such dyke-like extensions would be portions drawn out by crushing just as a crystal of felspar is drawn out in many gneisses.

Against the general acceptance of such a theory there is the objection that certain of the Archaean and early periods are characterized by just such volcanic rocks as are to be found in Prieska, great masses of lavas and clastic igneous rocks of all sorts. If any of such volcanic areas owe their rocks to meteors, it is certainly probable that the masses of planetary matter were grouped in swarms which would produce the same effect on the whole as a general outburst of great volcanoes over the earth. Each swarm would gradually discharge the individual bolides as the earth in its course round the sun came within attracting distance, and when the swarm was exhausted or passed out of reach of the earth's attraction, then there would be a secession of the production of these igneous rocks and normal sedimentation would take place.

In conclusion I must repeat that I do not contend that I have proved the meteoric origin of the amygdaloidal melaphyres of Prieska; but I maintain that the facts that we now know force us to take into consideration, when dealing with these extensive tracts of molten material on the surface of the earth, their possible origin from the collision of large meteorites. Everywhere we look in the older rock systems, we find enormous deluges of igneous material which are difficult to explain on the theory that the mass came from the interior of the earth, such as, for instance, the Bushveld igneous complex in the Transvaal; the object of this paper is to point out a possible cause in many cases, which so far has not been recognized.